

## AFWAL-TM - 83-174-FIMG

DESCRIPTIVE SURVEY OF HIGH SPEED FLOW SEPARATION

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FLIGHT DYNAMICS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
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#### FOREWORD

This report was prepared by Reservists assigned to the Aeronautical Systems Division (ASD) for the Air Force Wright Aeronautical Laboratories (AFWAL) located at Wright-Patterson Air Force Base, Ohio. The ASD Reserve Project number was 77-052.

The Air Force Project Monitor was Richard Neumann (AFWAL/FIMG) and the work was performed as part of Air Force Task 240407, "Aeroperformance and Aeroheating Technology". Richard Neumann formulated the project, guided our efforts, and continually supported the needs of the project. The authors thank Richard Neumann and James Hayes (AFWAL/FIMG) for their substantial contributions to this project.

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This memorandum has been reviewed and is approved.

. CHRISTOPHER BOISON

Chief, High Speed Aero Performance Branch

Aeromechanics Division

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# Section I INTRODUCTION

Flow separation can substantially alter the anticipated pressure and heating loads on high speed aircraft surfaces, and can compromise the design of high speed vehicles. The importance of this problem is well recognized and has prompted several hundred scientific investigations of various aspects of separated flow phenomena. Many of these investigations are listed and categorized herein. Investigations of lee side separated flow phenomena, however, are not included.

Three major portions of this report are: 1) the inverse chronologic listing of reports of high speed separated flow investigations, 2) a descriptive table and discussion of the investigations of various aspects of high speed flow phenomena, and 3) a reference list emphasizing the more recent investigations. We have also included a cross reference list of first authors and date of report. These are described in more detail in the following text. This report is useful in describing features of various aspects of high speed flow separation phenomena and delineating recent and appropriate references.

#### Section II

#### LITERATURE SEARCHES

Many library searches were accomplished in gathering material pertinent to high speed flow separation. "Key Words" were used to obtain bibliographies from: the U. S. Air Force, the U. S. Navy, NASA, the American Institute of Aeronautics and Astronautics (AIAA), and Grumman Aerospace Corporation. The proliferation of reports prompted our formulating a computer program for listing the reports in an orderly fashion (reverse chronological and alphabetical by author). In addition to the various library searches, reference lists from each report were reviewed to obtain additional references pertinent to high speed flow separation.

Emphasis has been placed on the more recent investigations, although landmark older references are also listed. The computer printout lists the date, year and month, of the reference, and the first 18 letters of the title. Numbers following the date are simply a numerical listing, alphabetically by author of the reports issued in a particular month. To our knowledge, this is the most complete listing of investigations of high speed flow separation phenomena currently available.

Date, Authors, and initial portions of report titles are listed in Table I, "Chronologic List of Reports."

#### Section III

## DESCRIPTION OF TYPES OF SEPARATION AND INVESTIGATIONS

Experimental and theoretical investigations of high speed flow separation phenomena are listed and categorized in Table II. The date is the same as that given in the computer listing (Table I), but the names of the first authors have been reduced to just the first eight letters. Thirty-five categories are used to delineate features of each report. These separated flow phenomena and selected investigations are described below. Only a few investigations are singled out for specific examples but every reference listed was carefully reviewed.

The letters in the table are the same as the first letter of the column heading; an aid in reading the tables. Column headings are described below.

The first four columns describe the general nature of the report. Included under "survey" are reports that include much information gleaned from many other investigations. One of the more outstanding survey reports, because of its thoroughness, is that prepared by Ryan. Of course, most reports in this complex field are experimental in nature. The theoretically oriented reports deal primarily with two-dimensional flows. Many of the theoretical reports lean heavily on numerical analyses and computer codes. Even though a numerical program is operational at one facility, it may require much work to make it operational at another facility.

Two-dimensional and axisymmetric separated flows are somewhat similar in theory. Conical flares or rocket exhaust plumes being the axisymmetric counterpart of two-dimensional ramps, flaps, or external burning. Much theoretical work in this area has been accomplished by Holden. Many have conducted experimental investigations and an empirical data base, along with analytical methods, has been established for predicting pressure and heat transfer distributions. The methods are practically useful for engineering needs, but it should be noted that the steadiness of two-dimensional separated flows is questionable. Indeed, Ginoux shows evidence of three-dimensional flow effects at reattachment of pseudo two-dimensional separated flows.

Three-dimensional separated flows are untenable to purely theoretical methods. There are, however, many numerical methods (such as those of Hankey, Shang et al) and analytical empirical methods (such as those of Neumann and Hayes) for predicting adequately facets of three-dimensional separated flows. Flap aspect ratio and end plate effects are discussed in several reports (Ball, Cassel, Kaufman, Neumann and others).

Hankey, Shang, and others have addressed the corner flow problem, numerically. This is treated as a conical flow and is different from the disturbance caused by a fin mounted on a surface (Korkegi, Neumann and others).

Edwards, Kaufman, Whitehead, and others investigated wing sweep effects on separated flows ahead of trailing edge controls. These effects are most pronounced when there is a change in the character of the boundary layer over the surface (from laminar outboard to turbulent inboard, transition occurring parallel to the swept leading edge).

NASA, the Air Force, other government agencies, and many private corporations have written "white papers" on high speed aircraft and missile design, and incorporation of the vehicle design with the (scramjet) propulsion system.

Chapman, Sterrett, Zukoski, and many others have investigated separated flows ahead of forward facing steps. These flows are now fairly well understood and their characteristics predictable for practical engineering purposes. Separated flows ahead of ramps or flaps pose a far more severe theoretical problem (the reattachment location is unknown initially). Furthermore, there is an unsteadiness in these flows that can cause control "buzz". Nevertheless, there is a wealth of experimental data useful in pinning down salient aspects of the flows.

There are many varieties of "base" flows. This category includes: rearward facing steps, blunt bases of axisymmetric bodies, flows over sharp expansion corners, wake flows and plume induced flow separation (which may also be included under "ramp"). Many base geometries and flow parameters proliferate a numerous variety of flows, precluding inclusive analyses of all such type flows. Of course many investigations provide guidelines, but an experimental approach for a particular vehicle and flow conditions still appears to be mandated.

The desire to release internal stores stably at high speeds has led to many investigations of cavity flows (Heller, Rossiter and others). Two-dimensional cavity flows and cavities on axisymmetric vehicles (applicable to high-altitude deceleration) have been investigated. However, the bulk of high speed cavity flow investigations pertain to flows past bomb bays. The steadiness of the flow and accoustics are important aspects of this problem. Criteria are available for analyzing and even predicting certain facets of cavity flows, but even fundamental scaling laws have yet to be established.

Ericsson, Stetson and others have performed many investigations of flows over forward facing spikes and cavities in nose cones. Again, stability of these flows is of paramount importance. Ablating nose cones are also considered under this heading.

Amick, Kaufman, Voitenko, Werle and others have performed experimental and theoretical investigations of flows past transverse jets. The jet fluid boundary has occasionally been represented as a forward facing step or, three-dimensionally, as a cylinder mounted perpendicularly to the surface.

Flows past protuberances from a surface have much practical significance and have accordingly received much attention. Some investigators that come to mind here are: Couch, Dolling, Gillerlain, Hayes, Kaufman, Korkegi, Lucas, Neumann and Waltrup. The shock wave associated with the protuberance separates the boundary layer from the vehicle surface and results in a complex viscid-inviscid three-dimensional flow field. Neumann and Hayes present practical methods for estimating the extent of separation and the increased pressure and thermal loads on a surface adjacent to sharp leading edge fins. The boundary layer character on the vehicle surface is an important parameter. For blunt fins, or cylinders, not only the character of the boundary layer but also its thickness relative to the fin height and diameter are important parameters.

The shock generated by a fin, or other protuberance, is incident to the boundary layer on the vehicle surface. Other incident shock-wave boundary-layer interactions are created by adjacent bodies, such as the shuttle and the main fuel pod, or stores mounted on wings. The two-dimensional case has been analyzed and "free interaction" theories developed that are reliable. Three-dimensional interaction cases are more complex and frequently require interpolation between sets of experimental data. In our experience, the

extent of the three-dimensional viscid-inviscid interaction flow region is considerably larger than would be anticipated using inviscid flow analyses.

Edney made the definitive investigation of shock impingement. The shock wave ahead of a protuberance separates the boundary layer form the surface. The "dead air" region forms an effective wedge and gives rise to a shock wave. This secondary shock wave impinges on the protuberance shock wave. A slip line starting at the juncture of the shock waves impinges on the protuberance leading edge. The energy of this small portion of the flow field is enormous and results in extremely large heating rates locally at a particular spot on the protuberance leading edge (Fig. 1). Indeed, the destruction of a ventral fin on the X-15 was a result of this type of flow interaction. The interaction also results in local high pressure regions on the surface ahead of the fin. Various types of shock impingement interaction flows can occur. These were categorized by Edney and investigated by him, Keyes. Voitenko, and others.

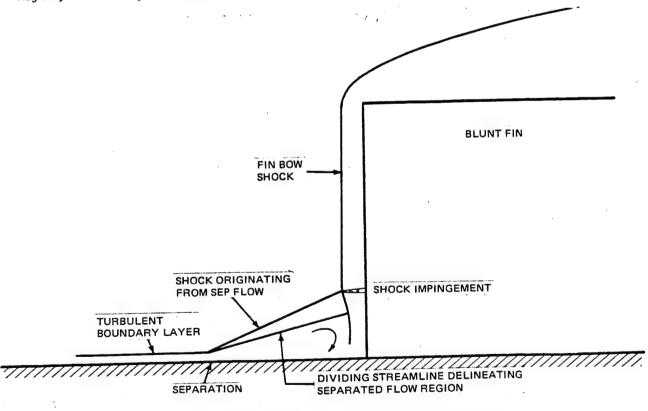


Fig. 1 Centerplane Sketch of Flow Separation and Impingement on a Blunt Leading Edge Fin

As would be expected, boundary layer characteristics are of paramount importance in shock-wave boundary-layer interaction flows. The definitive work here is that of Chapman, though many theoretical and experimental investigations have advanced knowledge in these types of interactions since Chapman's work. Transitional boundary layers are not as readily amenable to theoretical analyses as either laminar or turbulent boundary layers, but are prevalent in wind tunnel experiments. Indeed, the extent of transition is frequently comparable to the extent of laminar boundary layer flow. The lower case "t" used in this column is simply to distinguish it from the adjacent upper case "T" used for turbulent boundary layer interaction flows.

The vast majority of experiments have been conducted using wind tunnels; flight test is considerably more complicated and expensive.

The following columns indicate the type of information presented, whether calculated or measured. Surface static pressure and heat transfer rate distributions are most common. Flow field characteristics, whether calculated or measured, are harder to obtain and therefore appear less frequently in the literature.

The column headed "SCHL-SHD" pertains to all and any type of flow field photograph: schlichting, shadowgraph, interferrograph, holograph, or vapor screen.

Surface oil flow photographs and motion pictures delineate not only the extent of separation but many other features of the interaction flow. These features include the character of the boundary layer (laminar, transitional, or turbulent), the steadiness and stability of the interaction flow, surface streamline directions, and the extent of influence of the interaction flow. Ericsson, Gillerlain, Hayes, Kaufman, Kitchens, Neumann, Sedney and Winkelmann are just a few who have used the surface oil flow technique successfully.

Carriere, Chapman, Gadd, Hung, and several others have formulated expressions for the extent of separation as well as the "free interaction" pressure rise at the onset of separation. These correlations are generally adequate for engineering purposes.

A few reports touch upon other topics, and are usually described more fully under "Notes." These are self-explanatory.

An author-chronologic cross reference list is given in Table III to facillitate recalling the works of specific scientists in this field.

#### Section IV

#### CONCLUSIONS

Many investigations of high speed flow separation were reviewed. Salient aspects of interaction flows are discussed. Pertinent references are categorized in a descriptive table.

This reference work was designed to be a useful tool for aerodynamicists interested in the effects of high speed flow separation. At the least, it narrows the number of references to be reviewed in a particular effort involved with a particular aspect of high speed separated flow phenomena.

# TABLE I CHRONOLOGIC LIST OF REPORTS

8203		ERICSSON REDING	DYNAMIC SIMULAT
8201	1	HORSTMAN SETTLES W	A REATTACHING F
8201	2	SETTLES WILLIAMS B	REATTACHMENT OF
8201	3	SHANG HANKEY SMITH	FLOW OSCILLATIO
8111	0	DODS COE	CROSSFLOW EFFEC
8110		TAI	DETERMINATION O
8109	1	HUNG CHAUSEE	COMPUTATION OF
8109	2	KAUFMAN JOHNSON	METHODS FOR EST
8108	2	COUSTEIX HOUDEVILL	SINGULARITIES I
8105	1	DOLLING BOGDONOFF	SCALING OF INTE
8105	2	ERICSSON	AEROELASTICITY,
8104	1	MEIER GRONAU	VISCOUS AND INT
	2	TOBAK PEAKE	TOPOLOGY OF THR
8104	~	RIEBE PITTMAN	AERODYNAMIC CHA
8103	4	DOLLING BOGDONOFF	UPSTREAM INFLUE
8101	1		AN EXPERIMENTAL
8101	2	NESTLER	PROTUBERANCE HE
8101	3	NEUMANN HAYES	UPSTREAM INFLUE
8101	4	SETTLES PERKINS BO	
8101	5	ZUMWALT	EXPERIMENTS ON
8012		ARDONCEAU ALZARY A	CALCUL DE L'INT
8011	1	BRANDEIS ROM	THREE-LAYER INT
8011	2	DAVIS MALCOLM	TRANSONIC SHOCK
8010		BOGDONOFF SETTLES	SEPARATED FLOW
8008	1	CASSEL MCMILLEN TA	FINITE SPAN EFF
8008	2	HANKEY SHANG	ANALYSES OF PRE
8008	3	HUSSAINI BALDWIN M	ASYMPTOTIC FEAT
8008	4	MATEER VIEGAS	MACH AND REYNOL
8007	1	CASSEL JARRETT	HYPERSONIC FLOW
8007	2	GOLDSTEIN	WORKSHOP REPORT
8007	3	PEAKE TOBAK	THREE-DIMENSION
8007	4	SETTLES PERKINS BO	INVESTIGATION O
8006	1	MACIULAITIS	IMPROVED PREDIC
8006	2	SHILOH SHIVAPRASAD	MEASUREMENTS OF
8006	3	TIPTON	WEAPON BAY CAVI
8004	1	JARRETT CASSEL MCM	
8004	2	SIMPSON CHEW SHIVA	MEASUREMENTS OF
8003	1	JOHNSON KAUFMAN	HIGH-SPEED INTE
8003	2	KUHN	CALCULATION OF
8003	3	PAYNTER	ANALYSIS OF WEA
8003	4	PEAKE TOBAK	THREE-DIMENSION
8003	5	REDING GUENTHER JE	
8001	1	CLARK KAUFMAN MACI	AEROACOUSTIC ME
8001	2	HUNG CLAUSS	THREE-DIMENSONA
8001	3	MARCONI	SUPERSONIC INVI
8001	4	ROSEN PAVISH ANDER	
8001	5	SICLARI	INVESTIGATION O
7912	1	CEBECI KHALIL WHIT	
7912	2	KIRCHNER	ANALYTIC INVEST
7911	1	DYMENT	UNSTEADY PROPER
7911	2	HORSTMAN HUNG	COMPUTATION OF

TION THROUGH ANALYTIC FREE SHEAR LAYER IN C A COMPRESSIBLE TURB ONS OF SPIKE-TIPPED B CTS ON STEADY AND FLU OF THREE-DIMENSIONAL SUPERSONIC TURBULENT TIMATING PRESSURE AND IN THREE-DIMENSIONAL ERACTIONS OF CYLINDER INCLUDING DYNAMIC E TERACTING FLOW FIELD REE-DIMENSIONAL SEPAR ARACTERISTICS OF A HY ENCE SCALING OF SHARP \_ STUDY OF CAVITY FLO EATING AT HIGH MACH N ENCE SCALING OF 2D + THREE-DIMENSIONAL SE TERACTION ONDE DE CHO TERACTIVE METHOD FOR K-WAVE/BOUNDARY-LAYER AND BOUNDARY LAYER R FECTS ON FLAP HEATING ESSURE OSILLATIONS IN TURES OF SHOCK-WAVE B LDS NUMBER EFFECTS ON W OVER SMALL SPAN FLA T FOR THE AIAA 5TH AE NAL INTERACTIONS AND OF THREE DIMENSIONAL CTION OF FREQUENCY MO F THE TRANSVERSE VELO ITY NOISE ENVIRONMENT FECTS ON FLAP HEATING F A SEPARATING TURBUL ERFERENCE HEATING LOA SEPARATED TURBULENT AK GLANCING SHOCK/BOU NAL INTERACTIONS AND ON FLUCTUATING PRESSU EASUREMENTS FOR MACH AL PROTUBERANCE INTER ISCID CONICAL CORNER CHNIQUE FOR PREDICTIN OF CROSSFLOW SHOCKS O SEPARATED BOUNDARY-L TIGATION OF HYPERSONI RTIES OF SEPARATED PL THREE DIMENSIONAL TU

7911	3	IKAWA
7911	4	SHAW
7911	5	TASSA SANKAR
7910	1	CRAWFORD
7910	2	HUNT LAWING MARCUM
7910	3	KAUFMAN
7909	1	DELERY
7909	2	REDING
7908	_	MAUK
7907	1	LEGENDRE
7907	2	MODARRESS JOHNSON
7907	3	SHANG HANKEY PETTY
7906	1	CASSEL DUNCAN LAHT
7906	2	CHOM
	3	KIRCHNER
7906		NASH SCRUGGS
7906	4	ROSE MURTHY
7906	5	SCHEPERS PFEIFFER
7906	6	
7906	7	SCHWEIGER ERHARDT
7906	8	SETTLES FITZPATRIC
7905	1	ERICSSON ALMROTH B
7905	2	NEUMANN HAYES
7903		KAUFMAN JOHNSON
7902	1	CLARK
7902	2	SCIBILIA DUROX
7902	3	SHEN
7901	1	DOLLING COSAD BOGD
7901	2	EDITORIAL STAFF
7901	3	GILLERLAIN
7901	4	HANKEY SHANG
7901	5	HORSTMAN HUNG
7901	6	JOHNSON KAUFMAN
7901	7	ROSEN PAVISH ANDER
7901	8	RUDMAN
7812		DEVEIKIS BARTLETT
7811	1	EATON JEANS ASHJAE
7811	2	ERICSSON
7811	3	HABERCOM
7810	1	ERICSSON
7810	2	HUNG MACCORMACK
7810	3	VAN DEN BERG (ED)
7809	1	DOLLING COSAD BOGD
7809	2	FIORE
7809	3	LEGENDRE
7808	1	HAYES NEUMANN
7808	2	JOHNSON KAUFMAN
7808	3	KAUFMAN KIRCHNER
7808	4	LITTLE
7808	5	MORRISETTE GOLDBER
	,	MELCON

NELSON

7808

REAL GAS LAMINAR BOUNDARY-LAYER SEP SUPPRESSION OF AERODYNAMICALLY INDU EFFECT OF SUCTION ON A SHOCK SEPARA SOME RECENT DEVELOPMENTS IN THE PRE PERFORMANCE POTENTIAL AND RESEARCH PRETEST REPORT FOR HEAT TRANSFER EX ANALYSIS OF THE SEPARATION DUE TO S FLUCTUATING PRESSURES ON MILDLY IND BOUNDARY LAYER SEPARATION. CITATION SEPARATION OF A FLOW ALONG A LINE O INVESTIGATION OF TURBULENT BOUNDARY THREE-DIMENSIONAL SUPERSONIC INTERA HYPERSONIC INTERFERENCE FLOW FLIGHT SEPARATED FLOW PROBLEMS WITHIN THE COMMENT ON 'WALL SHEAR STRESS MEASU CALCULATION OF TIME DEPENDENT FLOWS REPLY BY AUTHORS TO R D KIRCHNER FLOW FIELD INVESTIGATIONS IN CORNER SHOCK-SHOCK AND SHOCK-BOUNDARY LAYE DETAILED STUDY OF ATTACHED AND SEPA HYPERSONIC AEROTHERMOELASTIC CHARAC AERODYNAMIC HEATING IN THE FIN INTE PRESSURE AND THERMAL DISTRIBUTIONS EVAUUATION OF F-111 WEAPON BAY AERO ETUDE DE LA FORMATION D'UN DECOLLEM SUPERSONIC FLOW OVER A DEEP CAVITY THE SCALING OF 3D BLUNT FIN INDUCED U.S. AIR FORCE RESEARCH AND DEVELOP FIN CONE INTERFERENCE FLOW FIELD THE NUMERICAL SOLUTION TO PRESSURE COMPUTATION OF THREE DIMENSIONAL TU HIGH SPEED INTERFERENCE HEATING LOA A CORRELATION TECHNIQUE FOR PREDICT THREE DIMENSIONAL SHOCK WAVE INTERA PRESSURE AND HEAT-TRANSFER DISTRIBU A WALL-FLOW-DIRECTION PROBE FOR USE ASYMMETRIC UNSTEADY FLOW IN FORWARD FLOW REATTACHMENT. A BIBLIOGRAPHY W FLOW PULSATIONS ON CONCAVE CONIC FO NUMERIC SOLUTION OF THREE-DIMENSION EUROPEAN RESEARCH PROGRAMME ON VISC THREE-DIMENSIONAL SHOCK WAVE TURBUL BOUNDARY LAYER EFFECTS SEPARATION OF A FLOW ALONG A LINE O TURBULENT HEAT TRANSFER DUE TO THRE HEAT TRANSFER DISTRIBUTIONS INDUCED SURFACE HEAT TRANSFER DISTRIBUTIONS SEPARATION TESTING OF LARGE WEAFONS TURBULENT-FLOW SEPARATION CRITERIA THE INFLUENCE OF A WAKE SPLITTER PL

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MENSIONAL JET INTERACTION WIT ISUALIZATION STUDIES OF A FIN SHUTTLE SYSTEM: RCS AUGMENTAT ESIGN ASPECTS OF HYPERSONIC V IGATION OF LAMINATE BOUNDARY-ENT BOUNDARY-LAYER SEPARATION ONIC TURBULENT FLOW REATTACHM AR SONIC LATERAL JET INTERACT S INTERACTION PHENOMENA IN SU CTIONS BETWEEN SHOCK WAVES AN ENTNYY FOGRANICHNYY SLOY V SV ONIC INTERACTION ALONA A RECT CK IMPINGEMENT HEATING AND RE OF LAMINAR VISCOUS INVISID I IGATION OF LAMINAR AND TURBUL NTERACTION RESEARCH, USN AAC. SONIC AERODYNAMIC CHARACTERIST TICAL EVALUATION OF ANALYTIC M HOD FOR ANALYZING THE INTERACT NTERACTION CONTROL EFFECTIVENE ME PROPERTIES OF REATTACHING L URES AND HEAT TRANSFER ON A 75 INDUCED SEPARATION, PROC.R.SOC SONIC PLANE STREAMS SEPARATED NTS ON A REATTACHMENT CRITERIO SONIC TURBULENT BOUNDARY-LAYER FIELD MEASUREMENTS DOWNSTREAM TRANSFER TO STEPS AND CAVITIES ISTENCE OF AXISYMMETRIC SEPARA ES IN TWO-DIMENSIONAL FLUID IN IMENTAL INVESTIGATION OF SEPAR SONIC-TURBULENT BOUNDARY-LAYER VESTIGATION OF THE EXTENT OF L RECENT RESEARCH WITH VISCOUS I -DIMENSIONAL VISCOUS INTERACTI SPEED FLOWS OVER WEDGES AND FL ETICAL AND EXPERIMENTAL STUDIE SONIC, TURBULENT BOUNDARY LAYE SONIC VISCOUS FLOW OVER CONCAV LENT BOUNDARY LAYER SEPARATION IMENSIONAL JET-INTERACTION EXP ACTION BETWEEN HIGH SPEED FLOW RY OF THE AEROTHERMODYNAMIC IN T HIGH SPEED GASDYNAMIC RESEAR NFLUENCE OF SHOCK WAVE-BOUNDAR ISTENCE OF AXISYMMETRIC SEPARA RCH AND ANALYSIS IN THE GENERA HYSICAL PROPERTIES OF A FLOW I SONIC SEPARATED FLOWS OVER WED SHAPE OF THE SEPARATED FLOW REGION

6901	5	
6900		THOMKE ROSHKO
6812	1	WHITEHEAD KEYES
6812	2	YOUNG KAUFMAN KORK
6811	1	DEARING HAMILTON
6811	2	LAMB HOOD
6811	3	MARKARIAN
6811	4	WALLACE
6810	7	KAUFMAN KOCH
	4	BUSHNELL WEINSTEIN
6809	1	
6809	2	CLAYTON WUERER
6809	3	
6809		ROSE MURPHY WATSON
6809		VOITENKO
808		CARRIERE SIRIEUX S
8086	2	DEARING HAMILTON
6808	3	HARVEY
4808		KEYES GOLDBERG EME
		NESTLER
6807		GLAGOLEV ZUBKOV PA
6807		MEYER
6807	7	WESTKAEMPER
	3	LAWRENCE WEYNAND
6806		
6806	2	LITTLE GRIFFITH
808		NESTLER SAYDAH AUX
6805	1	LEES
6805	2	
6805	3	VOITENKO
6804		BUSHNELL
6803	1	BAUM
		ИОЗИНОС
6803		SHEERAN DOSANJH
6802	1	BALL KORKEGI
6802		EDNEY
6802		HAMA
		SPAID ZUKOSKI
6801		
6801	2	BLOOM (ED)
6801		EDNEY
6801		GOLDMAN MORKOVIN S
6801		HOLDEN
6801		LEWIS KUBOTA LEES
6801		NESTLER
6801	8	STRIKE
6801	9	WALTRUP HALL SCHET
		WERLE
6800		CARRIERE SIRIEIX S
6800		KLINEBERG
6800		REYHNER FLUEGGE-LO
6712	1	BALL

FLOW VISUALIZATION AND CONTROL EFFE INCIPIENT SEPARATION OF A TURBULENT FLOW PHENOMENA AND SEPARATION OVER EXPERIMENTAL INVESTIGATION OF INTER HEAT TRANSFER AND PRESSURE DISTRIBU AN INTEGRAL ANALYSIS OF TURBULENT R HEAT TRANSFER IN SHOCK WAVE-BOUNDAR A REVIEW OF THE ANALYTIC METHODS AP HIGH SPEED FLOWS PAST TRANVERS JETS CORRELATION OF PEAK HEATTING FOR RE FLOW SEPARATION IN HIGH SPEED FLIGH SLOT JET INTERACTION STUDIES OF AN INTERACTION OF AN OBLIQUE SHOCK WAY INFLUENCE OF MACH NUMBER ON FLOW IN PROPRIETES DE SIMITUDE DES PHENOMEN EFFECT OF HINGE LINE BLEED ON HEAT EXPERIMENTAL INVESTIGATION OF LAMIN TURBULENT HEAT TRANSFER ASSOCIATED CORREATION OF TURBULENT HEAT FLUX T SUPERSONIC FLOW OVER AN OBSTACLE IN ROCKET EXPERIMENTS ON THE HEAT TRAN TURBULENT BOUNDARY-LAYER SEPARATION FACTORS AFFECTING FLOW SEPATION IN EFFECT OF MASS TRANSFER ON RAMF-IND HEAT TRANSFER TO STEPS AND CAVITIES VISCOUS EFFECTS AND HEAT TRANSFER I PENETRATION AND INTERACTION OF A TR THE EXISTENCE OF SUPERSONIC ZONES I EFFECTS OF SHOCK IMPINGEMENT AND OT AN INTERACTION MODEL OF A SUPERSONI PRESSURE AND FLOW-FIELD STUDY AT MA OBSERVATIONS ON JET FLOWS FROM A TW AN INVESTIGATION OF THE EFFECT OF S ANOMALOUS HEAT TRANSFER AND PRESSUR EXPERIMENTA STUDIES ON THE LIP SHOC A STUDY OF THE INTERACTION OF GASEO AN EXPERIMENTAL INVESTIGATION OF TH STRONG INTERACTIONS IN AERODYNAMICS EFFECTS OF SHOCK IMPINGEMENT ON THE UNSTEADY CONTROL SURFACE LOADS OF L LEADING-EDGE BLUNTNESS AND BOUNDARY EXPERIMENTAL INVESTIGATION OF SUPER CORRELATION OF TURBULENT HEAT FLUX ANALYSIS OF THE AERODYNAMIC DISTUBE FLOW FIELD IN THE VICINITY OF CYLIN A CRITICAL REVIEW OF ANALYTICAL MET SIMILARITY PROPERTIES OF THE LAMINA THEORY OF LAMINAR VISCOUS-INVISCID THE INTERACTION OF A SHOCK WAVE WIT WALL TEMPERATURE EFFECT ON INCIPIEN

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5500		SCHLICHTING	BOUNDARY LAYER THEORY (MCGRAW-HILL)

TABLE II - FEATURES OF REPORTS

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AUTHOR	HUSSAINI MATEER CASSEL J GOLDSTEI PEAKE TO SETTLES MACIULAI SHILOH S TIPTON JARRETT SIMPSON JOHNSON KUHN PAYNTER PEAKE TO CLARK KA HUNG CLA MARCONI ROSEN PA SICLARI CEBECI KIRCHNER DYMENT	
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AUTHOR	GLOTOV L KIRLIN SCHEPERS KEYES KORKEGI	SEDNEY K SETTLES KORKEGI NENNI OSKAM	BARYSHEV BIRCH RU CHIEN CLARK CZARNECK	MILLER AGARD CARTER CHU YOUN	KUCHEMAN ROSENBAU SPAID VATSA WE KENWORTH	
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AONES AUTHOR	KAUFMAN ROGERS B CHARWAT ELLIS RY LEES REE SILER DE GINOUX KAUFMAN ZUKOSKI EVANS KA HARTOFIL MECKLER STALLING KAUFMAN STALLING KAUFMAN KAUFMAN KAUFMAN KAUFMAN MILLER PATE KAUFMAN MILLER MILLER KAUFMAN	
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AUTHOR AUTHOR	BECKER K KAUFMAN SYKES GINOUX KAUFMAN WALKER S CURLE CARTER C STRIKE R	CHARWAT ROMEO ST NEWLANDE SOGIN BU STERRETT RHUDY HI MAULL SEDDON LARSON YIP	HAKKINEN VALLENII WISNIEWS CHAPMAN BLOOM PA	(,
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## TABLE III ALPHABETIC-CHRONOLOGIC CROSS REFERENCE LIST

ADDY	7212	01	AEROSPACE	7112	AEROSPACE	7000	01
AGARD	7802	01	AGARD	7511 01	AIELLO	7608	01
ALABAMA UN	6901	01	ALLAN	6801 01	ALSTATT	7705	01
ALPINIERI	6610	01	ALZNER ZAK	7006 01	AMICK	7005	01
AMICK	6910	01	ANDERSON	7212 02	APPELS	7309	01
ARDONCEAU	8012	0.	AVDUYEVSKI	6901 02	AYMER DE L	7807	01
BABER DRIV	7700	01	BALDWIN RO	7500 01	BALL	7110	01
BALL	6905	01	BALL	6712 01	BALL	6708	
BALL HANKE	6712	02	BALL KORKE	6802 01	BARNES DAV	6709	01
BARNES DAV	6707	OL.	BARYSHEV L	7512 01	BAUER FOX	7701	01
BAULLINGER	7610	01	BAUM	6803 01	BAUM	6612	01
	7009	01	BECKER KOR	6204	BECKWITH	6400	01
BECKER	7507	01	BERTRAM HE	6905 02	BILLING ORT	7208	01
BERTIN HIN			BIRCH KEYE	7208 02	BIRCH RUDY	7512	02
BILLIG ORT	7106	01	BLOOM (ED)	6801 02	BLOOM PALL	5708	
BLISS HAYD	7607	01	BLOOM (ED)	6905 03	BLOY GOERG	7402	01
BLOOM RUBI	7009	02		7312 01	BOGDONOFF	6701	01
BOGDONOFF	7505	01	BOGDONOFF	8010	BOGDONOFF	6210	
BOGDONOFF	5506	01	BOGDONOFF BOGGESS	7207 01	BORLAND	6608	01
BOGDONOFF	7506	01		8011 01	BREVIG	7303	01
BOVERIE	6903	01	BRANDEIS R BROADWELL	6305 01	BURBANK NE	6212	-
BREVIG STR	7301	01	BURGGRAF	7505 02	BURGGRAF O	7607	02
BURGGRAF	7608	02	BUSHNELL C	7700 02	BUSHNELL C	7603	01
BUSHNELL	6804	01	CARAFOLI P	6908 01	CARRIERE S	7504	01
BUSHNELL W	6809	01	CARRIERS E	6800 01	CARTER	7511	02
CARRIERE S	6808	01	CARRIERS C	7407 01	CASSEL DUN	7906	01
CARTER CAR	6110	01	CASSEL JAR	8007 01	CASSEL MCM	8008	01
CASSEL DUR	6909	01	CEBECI KHA	7912 01	CHANG	7805	01
CATHERALL	6609	01	CHAPMAN KU	5800	CHARWAT AL	6411	01
CHANG	6604	01	CHARWAT RO	6106	CHIEN	7512	03
CHARWAT DE	6107	01	CHOU SANDB	7307 01	CHOW	7906	02
CHILCOTT	6706	01	CHRISTOPHE	7507 02		7311	01
CHOW SPRIN	7609	01	CLARK	7902 01	CLARK	7512	04
CHU YOUNG	7511	03	CLARK KAUF	8001 01	CLAYTON WU	6809	02
CLARK DORA	7710	01	COLEMAN	7203 01	COLEMAN LE	7406	01
COAKLEY VI	7704	01	COLEMAN ST	7204 01	COLEMAN ST	7203	02
COLEMAN ST	7401	01	COOPER HAN	7410 01		6907	01
COOPER HAN	7707	01	COUSTEIX H	8108	COUSTEIX H	7511	04
COUCH STAL	6612	02 01	CRAIG ORTW	7104 01		7910	04
COVERT	7012		CURLE	6111	CZARNECK	7512	05
CRESCI RUB	6912	01 02	DAHLKE	7101 01		7310	01
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DEVEIKIS B	7801	01	DIAB SRINI	6906	01	DODGE LIEB	7707	02
DODS COE	8111	01	DOLLING BO	8105	01	DOLLING BO	8101	01
DOLLING CO	7901	01	DOLLING CO	7809	01	DOLLING CO	7801	02
DOLLING CO	7710	02	DOLLING CO	7707	03	DONALDSON	6706	02
DOUGHTY	7610	02	DRIFTMYER	7401	02	DRIFTMYER	7305	01
DRIFTMYER DYMENT	7201	01	DVORAK MAS	7703	01	DWOYER	7505	03
	7911 7609	01 02	DYMENT GRY	7709	01	EAST SMITH	7605	01
EAST (ED) EATON JEAN	7811	02	EAST (ED) EDITORIAL	7208 7901	04 02	EAST SMITH EDITORIAL	7700	03
EDNEY	6802	02	EDITORIAL	6801	03	EDITORIAL	7309	02
EICHELBREN	7402	02	ELFSTROM	7205	01	ELFSTROM	7503 7110	01 02
ELFSTROM	7109	03	ELLIS RYAN	6411	02	EMANUEL	6607	02
EMERY BARB	6705	01	EMERY LOLL	6511	01	ERDOS PALL	6206	01
ERICSSON	8105	02	ERICSSON	7811	02	ERICSSON	7810	01
ERICSSON	7708	01	ERICSSON A	7905	01	ERICSSON R	8203	OI
ERICSSON R	7604	01	EVANS KAUF	6409	01	EVANS KAUF	6207	01
FANNELOP	7508	-	FIORE	7809	02	FIORE	7707	04
FITZSIMMON	6608	02	FONTENOT	7603	01	FRANCIS	6507	01
FREEMAN KO	7506	02	GADD	~ 5703		GALLAGHER	7611	01
GAUTIER GI	7211	01	GERHART	7301	02	GILES THOM	6608	03
GILLERLAIN	7901	03	GILLERLAIN	7604	02	GILLERLAIN	7604	03
GILLERAIN	760 <b>7</b>	03	GILLETTE	6607	02	GILMAN	7104	02
GINOUX	6909	02	GINOUX	6905	04	GINOUX	6901	03
GINOUX	6609	02	GINOUX	6410	01	GINOUX	6202	01
GINOUX DOL	7501	01	GINOUX KOR	7506	03	GINOUX MAT	7402	03
GINOUX MAT	7305	02	GINOUX UEB	6605	01	GLAGOLEV P	7707	05
GLAGOLEV P	7700	04	GLAGOLEV	6807	01	GLOTOV LAV	7603	02
GOLDBERG	7311	02	GOLDBERG	7303	02	GOLDBERG	6711	01
GOLDBERG H	6910	02	GOLDMAN MO	6801	04	GOLDMAN OB	7310	02
GOLDMAN OB	7301	03	GOLDMAN OB	7205	02	GOLDSTEIN	8007	02
GOLUBINSKY	7608	04	GRANGE KLI	6706	03	GRAY	6608	04
GRAY RHUDY	7309	03	GRAY RHUDY	7103	01	GREEN	7000	02
GREENWOOD GUENTHER R	7403 7701	01	GUENTHER	6612	03	GUENTHER R	7712	01
GULBRAN RE	6507	02 02	GULBRAN RE	6703 7811	03	GULBRAN RE	6701	02
HAHN	6906	02	HABERCOM HAINS KEYE	7211	02	HABERCOM HAKKINEN G	7803 5903	01
HALPRIN	6502	UZ	HAMA	6802	03	HANKEY	7506	04
HANKEY	7402	04	HANKEY	7003	01	HANKEY	6702	01
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HANKEY CRO	6704	01	HANKEY HOL	7506	05	HANKEY SHA	8008	02
HANKEY SHA	7901	04	HANSEN (ED)	6405	01	HARTOFILIS	6409	02
HARTOFILIS	6305	02	HARTZUIKER	7204	02	HARVEY	6808	03
HASLETT KA	7207	02	HAVENER RA	7408	01	HAWK AMICK	6704	02
HAYES	7803	02	HAYES	7710	03	HAYES	7705	02
HAYES NEUM	7808	01	HEARTH PRE	7612	01	HEFNER CAR	7708	02
HEFNER STE	7211	03	HEFNER WHI	7212	03	HELLER BLI	7502	01
HIERS LOUB	6702	02	HILL	7012	02	HILL	6711	02
HODGE	7707	06	HODGE	7609	03	HODGSON	7012	03
HOELMER	6702	03	HOLDEN	7701	03	HOLDEN	7506	07
HOLDEN	7506	06	HOLDEN	7402	05	HOLDEN	7310	03
HOLDEN	7201	02	HOLDEN	6905	05	HOLDEN	6801	05
HOLDEN	6705	02	HOLDEN	6610	02	HOLDEN	6605	02
HOLLOWAY S	6511	02	HOLT LU	7407	02	HOPKINS	7409	01
HORSTMAN H	7911	02	HORSTMAN H	7901	05	HORSTMAN H	7701	04
HORSTMAN S	8201	01	HORSTMAN S	7708	03	HSIA	6610	03
HSIA SEIFE	6501	01	HUNG	7706		HUNG	7307	02
HUNG	7203	03	HUNG BARNE	7301	04	HUNG CHUSE	8109	01
HUNG CLAUS	8001	02	HUNG GREEN	7607	03	HUNG MACCO	7810	02
HUNG MACCO	7604	04	HUNT JONES	7303	03	HUNT LAWIN	7910	02
HUNT LAWIN	7801	03	HUSSAINI B	8008	03	IKAWA	7911	03
INGER	7711	01	INGER	7509	01	INGER	7507	04
INGER	7408	02	INGER	7408	03	INGER SWEA	7605	03
JARRETT CA	8004	01	JOHNSON	7007	01	JOHNSON	6803	02
JOHNSON	6608	05	JOHNSON BO	7106	02	JOHNSON KA	8003	01
JOHNSON KA	7901	06	JOHNSON KA	7808	02	JOHNSON KA	7506	08
JOHNSON KA	7409	02	JOHNSON LA	7704	02	JOHNSON MA	7411	01
JOHNSON TA	7709	02	JONES	6400	02	JONES HUNT	6602	01
KARAMCHETI	6311		KARASHIMA	7311	03	KAUFMAN	7910	03
KAUFMAN	7204	03	KAUFMAN	7004		KAUFMAN	6912	02
KAUFMAN	6904	01	KAUFMAN	6709	02	KAUFMAN	6608	06
KAUFMAN	6605	03	KAUFMAN	6602	02	KAUFMAN	6504	01
KAUFMAN	6410	02	KAUFMAN	6408	01	KAUFMAN	6407	01
KAUFMAN	6405	02	KAUFMAN	6402	01	KAUFMAN	6401	01
KAUFMAN	6401	02	KAUFMAN	6312	••	KAUFMAN	6310	01
KAUFMAN	6309	01	KAUFMAN	6309	02	KAUFMAN	6309	03
KAUFMAN	6202	02	KAUFMAN FR	7612	02	KAUFMAN FR	7506	09
KAUFMAN JO	8109	02	KAUFMAN JO	7903	02	KAUFMAN JO	7704	03 01
KAUFMAN JO	7412	01	KAUFMAN KI	7808	03	KAUFMAN KI	7804 7201	05
KAUFMAN KO	6810	0.5	KAUFMAN KO	7310	04	KAUFMAN KO	7301	02
KAUFMAN KO	7208	05	KAUFMAN KO	7202	01	KAUFMAN LE	7103	UΖ

KAUFMAN LE	7009	03	KAUFMAN MA	7807	02	KAUFMAN ME	6304	01
KAUFMAN ME	6611		KAUFMAN ME	6511	03	KAUFMAN ME	6501	02
KAUFMAN OM	6203	01	KAYSER	7408	04	KENWORTHY	7800	
KENWORTHY	7510	01	KESSLER RE	7107	01	KEYES	7601	01
KEYES	6909	03	KEYES GOLD	6808	04	KEYES HAIN	7305	03
KEYES MORR	7208	06	KHARCHENKO	7309	04	KIRCHNER	7912	02
KIRCHNER	7906	03	KIRKHAM HU	7700	05	KIRLIN	7603	03
KISTLER	6403	01	KISTLER TA	6700	00	KLINEBERG	6800	02
KLINEBERG	7205	03	KLINEBERG	6912	03	KLINEBERG	7401	03
KNOX KORKEGI	6511 7605	04	KOCH COLLI	7005 7605	02 04	KOOI	7700	06
KORKEGI	7600	03	KORKEGI	7507		KORKEGI	7601	02
KORKEGI	7311	01 04	KORKEGI	7203	05 04	KORKEGI	7504 7105	02
KORKEGI	7007	02	KORKEGI KRAUSE (ED)	7308	04	KORKEGI KUCHEMANN	6601	01
KUCHEMANN	7511	05	KUHN	8003	02	KUSH SCHET	7206	01
KUSSOY HOR	7502	02	LAMB HOOD	6811	02	LAPIN	7200	03
LAPIN	7000	03	LARSON	5911		LAW	7606	03
LAW	7506	10	LAKSON	7506	11	LAW	7506	12
LAW	7406	03	LAW	7401	04	LAW	7307	03
LAWING	7805	02	LAWING	7506	13	LAWRENCE W	6806	01
LEBLANC GL	7005	03	LEE BARFIE	7102	13	LEES	6805	01
LEES KUBOT	7209	01	LEES REEVE	6411	03	LEGENDRE	7907	01
LEGENDRE	7809	03	LEWIS KUBO	6801	06	LEWIS KUBO	6701	03
LIN RUBIN	7403	02	LITTLE	7808	04	LITTLE GRI	6806	02
LUCAS	7101	02	LUCERO	7001	01	LUMSDAINE	7303	04
MACIULAITI	8006	01	MAGER	5602	-	MAGNAN SPU	6604	02
MAISE ROSS	7408	05	MARCONI	8001	03	MARKARIAN	6811	03
MATEER VIE	8008	04	MAUK	7908		MAULL	6008	
MAURER	6511	05	MCCABE	6608	07	MCCABE	6508	
MCDONALD	6503	02	MCGREGOR W	7011		MECKLER	6712	03
MECKLER	6506		MECKLER	6409	03	MECKLER	6309	04
MEIER GRON	8104	01	MEYER	6807	02	MIKESELL	6608	80
MIKULLA HO	7605	05	MILLER	7512	06	MILLER	6310	02
MILLER HIJ	6402	02	MODARRESS	7907	02	MORKOVIN	6606	01
MORRIS KEY	7305	04	MORRISETTE	808	05	MURPHY	7101	03
MURPHY	6910	03	MURTHY ROS	7807	03	NAGEL BECK	7301	06
NAGEL FITZ	6608	09	NAGEL SAVA	6608	10	NARASIMHA	6711	03
NASH SCRUG	7906	04	NEEDHAM	6712	04	NEEDHAM ST	6606	02
NELSON	7808	06	NENNI	7600	02	NESTLER	8101	02
NESTLER SA	7507	`06	NESTLER	6808	05	NESTLER	6801	07
NESTLER SA	6907	02	NESTLER SA	6806	03	NEUMANN	7205	04

NEUMANN BU	6903 7801	02 04	NEUMANN HA NEUMANN TO	8101 7410	03 02	NEUMANN HA NEWLANDER	7905 6101	02 01
NEUMANN PA OMAN FOREM	7503	02	OSKAM	7600	03	OSKAM BOGD	7502	03
OSKAM VAS	7803	03	PAGE	6908	02	PAGE HILL	6705	03
PANARAS	7709	03	PANOV	6901	04	PATE	6403	02
PATTERSON	7711	02	PAYNTER	8003	03	PEAKE	7607	04
PEAKE RAIN	7611	02	PEAKE RAIN	7205	05	PEAKE TOBA	8007	03
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RAY	7310	05	REDA MURPH	7302		REDA MURPH	7206	02
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